Summary
of a
Proposal

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Submitted by: [redacted]

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Principal Investigator: [redacted] STAT

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Aspheric Optical Systems

It is proposed to investigate modern evaporation techniques for aspherizing optical surfaces and to study the advantages gained by using aspheric surfaces on all surfaces of an optical system. There have been several recent technological advances which make this approach appear feasible as a production method. These advances are:

1. The use of large computers to optimize designs. Aspheric surfaces can be handled as readily as spherical surfaces.

2. Vacuum techniques such as high pump speeds, large vacuum valves, electron beam heating.

Large computers can now correct optical systems in a few minutes. By placing aspherics on all the surfaces it should be possible to distribute the aberration correction in a way which would minimize the number of elements required.

In the past designers have always been guided by the philosophy that one could use only one aspheric surface. As a result the aspheric was used to correct large aberrations. It was seldom feasible to eliminate any elements by introducing an aspheric.

Evaporation techniques for making aspherics have attracted interest for several years. Appendix 1 is a review of several papers on the subject. This technique appears to be the most promising method for making aspherics economically for it lends itself to automatic methods of fabrication.

Scope of proposed research

A. Optical Design

It is proposed to investigate the use of aspheric surfaces on every surface of a triplet type of photographic lens. This lens is a basic fundamental type of lens. It has the minimum number of elements which allow the correction of all the third order aberrations. By placing aspherics on all the surfaces it should be possible to significantly improve on the all spherical triplet. The research would have the following objectives:

1. To arrive at optimum solutions for several types of triplets. For example, high speed narrow field types and low speed wide angle types.

2. To compare these designs with optimum all spherical elements of three and four lenses.

3. To study the feasibility of minimizing the aspheric deformations on all the aspherics. In the past aspherics have been confined to single surfaces resulting in large deformations. These large deformations have made them difficult to make and sensitive to positioning.

4. To study the use of aspheric surfaces to minimize the sensitivity of all elements to centering tolerances.

B. Evaporation Research

It is proposed to investigate the aspherizing of optical surfaces by depositing films on an optical surface by evaporation in a vacuum. In order to accomplish this it is required to deposit films which are quite thick with a precisely controlled refractive index and thickness over a large area of an optical surface. From the results of our own work in thin film optics at

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the [redacted] and from the results of other investigators, one can enumerate some problems which have to be overcome. These are considered below.

1. The evaporation of high quality thick films.

The films which are deposited for aspherizing are quite thick compared to the films which are used for interference coatings. For example, the total thickness of the films in a conventional metal-dielectric-metal interference filter is less than 2000A. However, in order to aspherize a surface, it might be necessary to deposit films which are twenty wavelengths or 100,000A thick. When such thick films are deposited, it has been found that not infrequently the optical quality of the films deteriorates and also that the stress builds up in the film until it often crazes or parts from the substrate. It is proposed to investigate a class of materials which do not deteriorate in optical quality and which also have good mechanical properties. One promising material is silicon monoxide. Although the mechanical properties of this material are excellent, it has been found that its refractive index depends strongly upon the partial pressure of the oxygen during the evaporation. Thus it is intended to utilize a commercially available pressure controller to maintain partial pressure of oxygen and hence the refractive index during the evaporation. Another class of materials which shows great promise are the glass formers. This includes such materials as boric oxide in the visible spectral region and compounds containing selenium, arsenic, and tellurium in the infrared. The materials will be evaporated from a water-cooled copper crucible with an electron-beam power source. Since the crucible is comparatively cool, the evaporant will not be contaminated with impurities from the crucible. The material is fed up from the bottom of the crucible so that large amounts of material can be evaporated. Since the electron beam produces extremely high temperatures, it is not difficult to evaporate refractory materials such as zirconia, sapphire and quartz.

2. Control of the contour of the aspherizing layer.

It is of paramount importance that the contour and hence the thickness of the aspherizing film be controlled precisely across the optical surface. This is usually accomplished by placing masks in front of the optical surface and rotating it while it is being coated. This mask has two functions: first, it compensates for the fact that certain portions of the surface are further away from the source and hence a unit area receives less material per unit time. Also, it varies the thickness of the film to produce the contour of the aspheric surface.

One of the common difficulties is that the amount of the material which is evaporated at each angle from the source is a function of the amount of material which is remaining in the crucible. Hence, as the evaporation progresses the angular distribution of the source changes. The mask which produces the aspheric film on the substrate is of course designed for a given source distribution and if this changes the errors are made in the contour of the aspheric surface.

This effect can be mitigated of course by rotating the substrate, often with some planetary gear arrangement, to average out this change in the distribution. However, this makes difficult to heat the substrate during the evaporation and still more difficult to measure the temperature and to make measurements optically _in situ_ of the asphericity. Thus it is proposed to utilize a source which is moving constantly during the evaporation. The difficulty of accomplishing this with conventional resistance heated sources is that it is difficult to move the heavy copper conductors which supply the large amounts of current to the source. However, since an electron gun is used, the power is transmitted at a high voltage (10,000) volts and the flexible leads to the electron gun source can be quite small.

C. If items A and B show sufficient promise it is proposed to build and aspherize a sample triplet to demonstrate the feabilility.

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Appendix 1

ASPHERIZING BY EVAPORATED FILM DEPOSITS

The use of evaporated films deposited non-uniformly over a surface to produce an aspherical element has been considered as early as 1936 when Strong and Gaviola[1] parabolized a spherical blank by evaporating aluminum onto it through a suitably cut baffle. Since that time much has been written on the use of aspherical[2] elements in transmission and reflection optics to produce fast optical systems having unusual characteristics.

Fundamentally, the problem of using evaporated films for forming aspherical elements resolves itself into two parts, each of which has been considered in the solution of entirely different problems. These are (1) the development of techniques for producing a desired distribution of evaporation over a surface, and (2) the production of thick films. The first problem has been dealt with primarily in an attempt to obtain uniformly thick films over large areas[3]. A deposit from a point evaporating source onto a plane substrate will vary in thickness as $\cos^3$ of the polar angle. If the source itself is plane, i.e., evaporates with a cosine distribution, then the thickness will fall off as the $\cos^4$. To compensate for this decrease in thickness three principal techniques have been employed: (1) multiple sources have been distributed around the system such that the total thickness varies only through small limits over a flat surface; (2) the substrate has been rotated about an axis perpendicular to its surface, and the source or sources offset from this axis; and (3) a rotating baffle, appropriately figured, has been placed between the source and the substrate. These techniques may in some instances be combined to give the best results. It might be mentioned that obtaining a uniform thickness in an evaporated film is in some respects similar to optically polishing an optical flat. If uniform rotation about an axis is employed, invariably there will be circular symmetry and radial non-uniformity. An interesting experiment would be to develop a randomly slipping rotation about a moving axis for driving the substrate.

If a figured baffle is to be used, no concern need be taken of the non-uniform characteristics of the course, since these can be incorporated in the design of the baffle. However, for reproducible evaporations careful attention must be paid to keeping the vacuum conditions and the rate of evaporation the same in all runs. If multiple sources are used care must be taken that the rates of evaporation from each is reproducible in different evaporations.

Since all the material that deposits on the baffle is lost, the baffle should be designed with the maximum open area compatible with the correction it has to supply. This is particularly pertinent for aspherics, where thick films might be needed, because of the difficulty and inconvenience in evaporating large quantities of a substance. Some aspects of baffle design and source distribution are discussed by Strong and Gaviola[1], by Schulz[4], and by Strong[3].

In addition to obtaining uniform films, non-uniform films have been used for parabolizing and hyperbolizing spheres, to the formation of linear and non-linear wedges[5], and for apodizing screens[6] to alter the diffraction characteristics of optical elements.

The second and more challenging problem, that of obtaining very thick evaporated films, is being attacked chiefly by those interested in interference filters in the infra-red[7]. When one attempts to convert a filter design from the visible to the infrared region he is compelled to increase the thickness of each layer in the ratio of the two wavelengths, Most films show some form of deterioration if their thickness is increased beyond a certain point, this point varying with the material and the conditions of evaporation. Transparent materials (non-metals) will either develop many cracks or take on a cloudy appearance. Highly reflecting materials (metals) form large crystals on their surface that are highly scattering. In general, non-metals can be deposited to a greater thickness than metals before deterioration sets in. This has led to the deposition of a dielectric, overcoated with a thin (but opaque) layer of highly reflecting metal to form an aspherical reflecting surface[8]. It might be pointed out that the tolerance on reflecting surfaces are considerably closer than for transmitting surfaces.

An attempt to overcome the necessity for thick films in parabolizing a sphere has led Schulz[9] to deposit an aluminum film stepwise, as in a Fresnel lens, to keep its thickness below the scattering point. If such a technique is contemplated careful attention will have to be given to the interference effects that will result.

A very interesting, and as yet unpublished, investigation has been carried out by Turner and Truby[10] to determine the cause of the deterioration in thick dielectric films. They deposited dielectrics on a 50 micron diameter glass rod supported at one end only, and found that the rod would bend under the stresses set up by the deposit. Some materials would deposit on the glass in films that showed tension, while others displayed compression. An accurate measure was made of the thickness at which the films broke up, when alternate layers of films in tension and compression were deposited, the first to a thickness somewhat less than that causing deterioration, the second to a thickness adequate to compensate for strain produced by the first. It was found in this way that composite films of many times the thickness possible with a single film were feasible.

Since these experiments were intended to demonstrate how it is possible to obtain complex films of greater thickness than possible with a single substance, the substrates on which the films were deposited were not heated. However, for many substances, the thickness at which deterioration occurs can be greatly increased by elevating the temperature of the substrate.

This investigation points a way for further investigation into the use of evaporated films for aspherical surfaces. One

One consideration that must not be overlooked if this method of producing thick films is used is the effect of interference between the different layers of the composite film. If layers with widely different indices of refraction are used, a marked variation of transmission with wavelength will result in general. To minimize this effect the composite film could be built of a great number of extremely thin layers of the order of 50-250 Ao. The theory of the reflection from a pile of repeating layers of arbitrary thickness has been worked out by Rayleigh[11]. In this way the visible region of the spectrum will be greatly separated from the first order wavelength toward the long wavelengths, so that only very small variations of transmission with wavelength will result for visible light.

Another obvious method of eliminating interference effects is to find materials with indices close to that of the substrate on which they are to be deposited. There are several oxides (WO_3, SiO) with indices only slightly higher than ordinary crown glass which might serve as alternating layers for aspherical surfaces. If two can be found with opposing stress characteristics, it should be possible to minimize interference in a thick film. One substance on which experiments could profitably be run is SiO. It's index is near that of common glasses and evaporated under suitable procedures gives a hard, transparent film. Al_2O_3 is another possibility, provided that successive layers of Al can be anodized completely[12].

The applicability of evaporated films for aspherical surfaces might be summarized by breaking it up into three categories of thickness each separated by an order of magnitude: If the optical thickness of correction required is of the order of 5 microns it can probably be formed from a single film; if it is of the order of 50 microns, it can probably be obtained from a strain compensated complex film; if it is of the order of 500 microns, its availability will depend on further investigations.

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